

3951

STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS



RADIOGRAPHIC INSPECTION OF
WELDED HIGHWAY BRIDGES

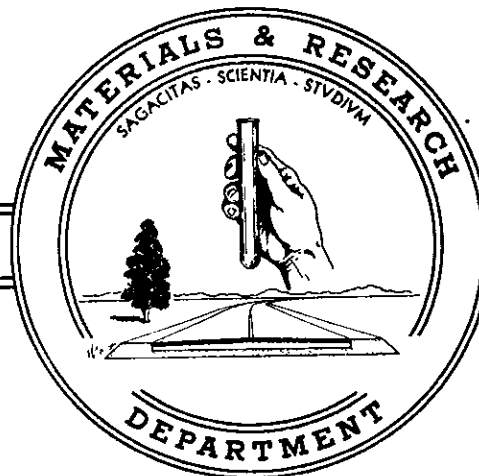
By

John L. Beaton
Supervising Highway Engineer

58-07



Meeting
yard
, 1958



RADIOGRAPHIC INSPECTION OF
WELDED HIGHWAY BRIDGES

By

John L. Beaton *

Synopsis

Procedures and standards for radiographic inspection as applied to welded structural steel highway bridges have not been clearly covered by any nationally accepted specification.

This paper outlines the procedure and standards followed by the California Division of Highways and develops data to indicate the necessity for uniform standards covering practical application to highway bridges.

A limited set of recommended standards are included in the paper.

* Supervising Highway Engineer, Structural Materials Section, Materials and Research Department, California Division of Highways. To be presented at the 37th Annual Meeting of the Highway Research Board, Washington, D. C. January 6-10, 1958.

Introduction

During the past ten years, the California Division of Highways has constructed 242 bridges containing 110,000 tons of welded structural steel, and at the present time has 56 bridges under contract which will require 42,000 tons of welded structural steel.

Radiography has been used as the primary nondestructive method of examining the major stress carrying butt welds of all of these structures. Its use, both as a working tool to locate and correct defects, and as a factor to insure the integrity of welded structures, has been successful. The cost of such radiographic work is nominal when considering the usefulness of the radiographs. However, a problem arises in the use of radiography because of the lack of universally accepted standards developed specifically for application to highway bridges. The purpose of this paper is to show the need for such standards and to offer a suggested approach to the problem.

The current edition of the American Welding Society's specifications for Highway and Railway Bridges (modified to a slight degree) is used to control the welded structural steel fabrication of the California Division of Highways. In accordance with these specifications the contractor is informed when radiographic inspection is to be performed and of the radiographic standards to be attained. The cost of the radiographic inspection is directly borne by the State.

As different types of bridge structures provide a variety of welded joints needing radiographic examination, it is difficult to quote a meaningful cost for such work based on tonnage of fabricated steel. A more realistic figure is the cost for each reported 4.5- by 17-in. radiographic plate. This is the standard size film used by California for bridge work. Presently, this radiographic work is costing an average of \$5.50 per film. In 1955 the cost was about \$7.50 per film, whereas in 1949 each exposure cost was approximately \$25.00.

This cost per radiographic picture will vary from \$2.00 per film to as high as \$7.00 per film depending on the thickness of joint, source of radiation, and ratio of travel time to radiographic time. These factors will be influenced by the size and design of each project and whether or not the radiographic work is done for shop fabrication or field erection.

In this State the actual radiography is performed in the shops by commercial laboratories under service agreement and in the field by State personnel equipped with the traveling unit shown in Figure 3. California has standardized on the use of a 4.5- by 17-in. radiographic plate.

Inspection Procedure

With the possible exception of two steps, the fabrication inspection procedure followed by the California Division of Highways is approximately the same as that in general use throughout the United States. The two steps which may represent differences are (1) a prefabrication conference and (2) the procedure used for radiographic inspection.

The California fabrication inspection procedure for welded steel bridges can be divided into five important steps:

1. Prefabrication conference, at which the methods and procedures to be followed by the fabricator and by the inspector during fabrication are discussed informally. The important details and requirements of the plans and specifications are thoroughly reviewed at this time and any differences of opinion are resolved in advance of the actual start of fabrication. This discussion is usually scheduled just before the shop drawings are submitted for approval.
2. Prequalification of manual weldors, automatic welding machine operators, and welding procedures. The first use of radiography is made during this period in that each butt welded qualification plate is radiographed before the mechanical tests are conducted. This not only shows what is meant by "radiographic quality" but also eliminates useless machining and testing of defective plates.

3. Identification of the steel to mill test reports by the inspector. Mill test reports are witnessed and verified by a representative of the State at the mill. Under specifications only a small amount of unidentified steel may be furnished, such steel is sampled and tested by State personnel. During this time especial emphasis is placed on a means of positive identification of special steels as they are cut for use throughout fabrication.
4. Continuous visual inspection, supplemented by nondestructive testing as necessary during actual fabrication. Penetrant dye, hardness testing, and radiography are the primary types of nondestructive tests used during actual fabrication. Approximately 80 percent (this may be increased or decreased depending on job experience) of all butt welds to be used in primary tension are radiographed, and a spot radiographic check of all such welds to be worked in compression is also performed (the amount depends on job experience). Radiography is not used on fillet welds. Butt welding is controlled by visual inspection supplemented by radiography, whereas fillet welding is controlled by visual inspection supplemented by the use of penetrant dye.

5. Final inspection before and after sandblasting, supplemented by an inspection after shipping to the site for possible shipping damage. This latter inspection is performed by the construction engineer, who will also include an "after sand-blasting" inspection if sandblasting is to be done in the field.

Need for Radiographic Bridge Standards

A random analysis of 5808 radiographic plates exposed during the fabrication inspection of California bridge structures shows that 7 percent of the welded butt joints were not acceptable. These defective joints occurred in spite of competent visual inspection and prequalification of both procedure and personnel, as well as full knowledge by the weldor that the weld was subject to radiographic inspection. It is considered that this figure would have been higher had the fabrication not been subjected to the discipline of radiography. It is true that probably some of the defective welds were already known by the inspector to be defective and that advantage was taken of the nonargumentative position an inspector assumes when backed by a radiograph. This, however, does not affect the fact that 7 percent of the welded joints designed to carry major tensile stress when first fabricated did contain serious defects.

At the present time Paragraph 707 of the 1956 Standard Specifications for Welded Highway and Railway Bridges of the American Welding Society states that the radiographic procedure technique and standards of acceptance shall be specified or shall conform to commercial practice. It is then stated as a footnote that the A.S.M.E. Boiler Code, Section VIII, Paragraph UW-51, is an example of such practice. This code is one of the few generally accepted commercial specifications in existence and is excellent for the purpose intended.

However, the joints of a highway bridge structure and of a pressure vessel are subjected to different types of loading, and while the standards for allowable defects in a welded joint of a pressure vessel are somewhat acceptable for a highway structure, there are several factors that need modification.

The first is porosity. While in a pressure vessel porosity requires separate consideration, in a bridge structure it is merely another defect and need be treated no differently than the inclusion of slag or other deleterious material. It is recognized that the uniform sides of a gas bubble are probably less likely to act as stress raisers than are the sharp edges of the hole caused by a piece of slag; however, at present it is not felt that sufficient information is available to justify the additional interpretation that would be made necessary by segregation. The major difference between the welded joints of a pressure vessel and those of a bridge is that the pressure vessel joint normally has no free edges, whereas a bridge structure joint often has two free edges. References 1, 2, and 3 in the bibliography indicate somewhat the effect of welding defects as well as the effect of free edges and points of restraint on the initiation of fatigue and static failures in welded joints.

In addition to the above points and of equal importance is the fact that the A.S.M.E. code does not lend itself readily to the required speed of quantitative analysis for bridge work.

It will be noted that this discussion is primarily concerned with allowable inclusions while other defects have been ignored. As is indicated in the suggested standard (Figure 1),

it is considered that cracks, lack of penetration, overlap, and incomplete fusion cannot be allowed. This is in accordance with both the A.W.S. and A.S.M.E. codes, and no change is suggested or considered desirable.

California Radiographic Procedure

The purpose of radiography in the welding inspection process is to show the presence and nature of defects in the interior of welds. This can be done, but to do it properly it is necessary to clearly define by a specification both the procedure and method of radiography to be used and also to define the acceptable size and distribution of such defects in a welded joint.

At the present time California follows the procedures outlined in Paragraph UW-51 of Section 8 of the A.S.M.E. Boiler and Pressure Vessel Code dated 1952, insofar as radiographic technique is concerned. California specifications further outline that lack of penetration, incomplete fusion, or cracks of any type are unacceptable. In addition, the presence of slag, porosity or other inclusions in excess of the limits specified in Paragraph 607 of the American Welding Society Specification D2.0-47 shall constitute cause for the rejection of such welds as defective.

There is no question but that any primary structural weld should not contain any of the first mentioned defects.

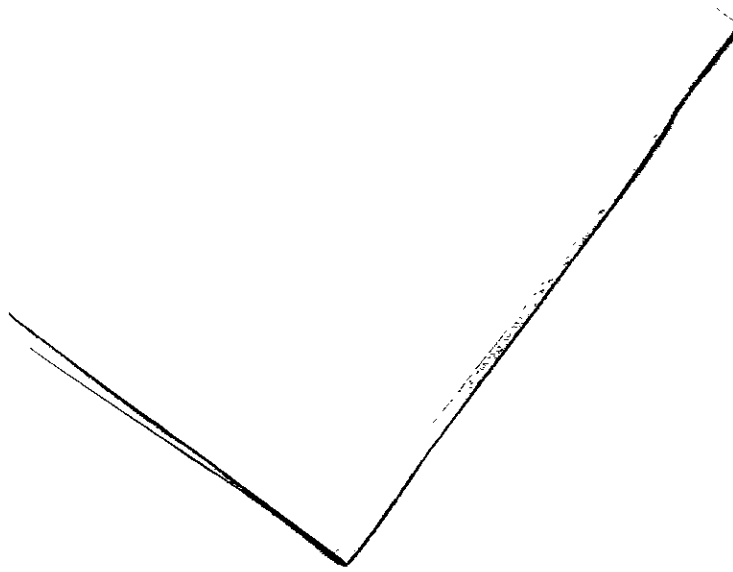
The second part of the specification, however, needs revision. It can be overly restrictive in the case of large defects but too lenient in some cases, such as over-all distribution of small defects or distribution of defects along a free edge or within an area of restraint. Probably one good reason for the unsuitability of this A.W.S. Paragraph 607 in the interpretation of radiographs lies in the fact that it was never intended for such application. Its intent was that it would be

applied to macrographic sections cut through the welded joint rather than to a projection of a summation of the defects on a flat plate such as is done in radiography.

Insofar as highway structures are concerned, the following points are considered to be most important in the technique for radiographic examination.

Radiography of highly stressed tension butt welds should be performed after the joint has been ground. Since all butt welded joints carrying primary tension stresses under California construction specifications must be ground, this does not result in any extra expense insofar as the radiographic procedure is concerned. Butt welded joints that need not be ground for stress carrying purposes may be radiographed in their as-welded condition. This means that the interpreter of the radiograph must be highly skilled so as not to confuse the surface irregularities with internal defects. For training purposes, typical radiographs of past work are used, supplemented by the collections of reference radiographs issued by A.S.T.M. (A.S.T.M. designation E 99) and by the International Institute of Welding issued by Tekniska Rontgencentralen. (References 7 and 8).

The radiographic technique to be followed must disclose all defects having a thickness equal to and in excess of 2 percent of the thickness of the base metal. In order to check this, at least two penetrameters must be used. The thickness of the penetrometer cannot be more than 2 percent of the thickness of the plate. The penetrameters are placed at each end of the area to be radiographed. They are both placed on the side of the joint nearest the source of radiation. In addition to this, the film must be



carefully identified by the use of lead numbers so that their image will appear on the film but shall not interfere with the interpretation of the film. The weld must also be marked by the weldor so that he can be held accountable for his work.

In addition to insuring that it will be possible to see the penetrometer, a technique must be followed that will guarantee a sharpness of image delineation. This is of utmost importance in the interpretation of a radiograph, especially if fine cracking is present. This sharpness of the image is determined primarily by the use of the proper source of radiation, film type, and exposure for the thickness of joint being radiographed.

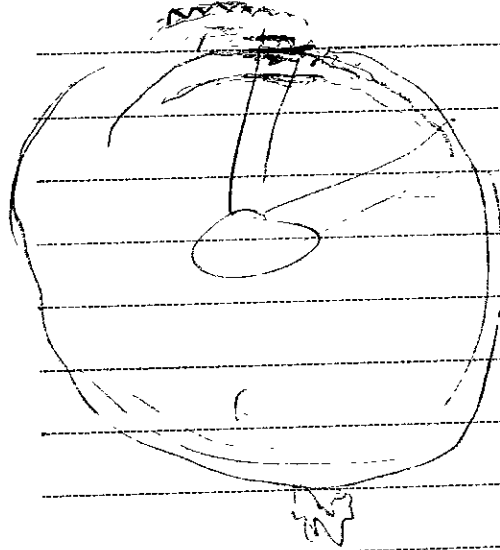
Radiography or any other form of nondestructive testing, while a useful tool to the bridge engineer and inspection, is nevertheless not the cure-all. It cannot be substituted for competent visual inspection. It can only be used to supplement such inspection. It has very definite limitations which must be recognized by all who use it. The possible inability of radiography to detect fine cracks is probably its most serious drawback. Since 2 percent sensitivity is about the maximum that should be expected practically from the radiograph, it can readily be understood how a fine crack in thick material may escape detection. This is one of the reasons why proponents of the use of ultrasonics in the field of nondestructive testing of structural welding are gaining recognition. Unfortunately, at the present time the use of ultrasonics in this field is limited by the lack of skilled technicians and a lack of education concerning the acceptance and interpretation of the results of ultrasonic measurements.

STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS

DISTRICT No.

MEMO.

19



Radiography is also limited in areas where varying thicknesses of metal must be penetrated, such as the fillet weld used in connecting a web to a flange. Once qualified, this type of weld lends itself better to visual inspection, supplemented by penetrant dye used to disclose the presence and extent of any possible cracking.

Proposed Radiographic Standards

In addition to simplification of inspection management, two structural factors have influenced the selection of the suggested standard of maximum inclusion to be used in the interpretation of radiographic film, as shown by Figure 1 in the Appendix of this paper. These are (1) the indications of restraint and the tendency of flange metal to yield in the area directly under a web or other stiffening medium and (2) the indications that a defect close to the edge of a tension stress carrying member tends to concentrate the stress flow lines more than if the defect is materially away from the edge of the joint.

Welded bridges are usually designed in accordance with A.W.S. Specification D2.0-56 (Specifications for Welded Railway and Highway Bridges) which cites no radiographic standards directly but does refer to the A.S.M.E. Boiler and Pressure Vessel Code. Because of this and the lack of quantitative data concerning the effect of weld metal discontinuities on the strength of a welded joint, it is not practicable to detail an engineered system of radiographic inspection which would be commensurate with the intended function of a bridge joint.

Consider the A.S.M.E. Boiler and Pressure Vessel Code, for example. Part UW-11 of the code states that all welded joints over $1\frac{1}{8}$ -in. thick, welded joints over 1-in. thick of the harder grades of carbon steel and of low alloy steels, welded joints in vessels designed for pressures in excess of 50 psi, and welded joints in vessels containing lethal substances should be radiographed throughout the entire length. (Nozzle and valve welds

included in this category are not pertinent to this discussion.) Joints other than these need only be spot examined by radiographic methods.

Assume that a $1\frac{1}{8}$ -in. welded joint is to be employed in such a manner that, in accordance with Part UW-11 of the code, it must be radiographed throughout its entire length. Paragraph M-2 of Part UW-51 states that radiographs of such a joint may show it to contain elongated slag inclusions up to $\frac{3}{8}$ -in. in length without providing cause for rejection of the weld. Paragraph M-3 specifies that the total length of slag inclusions in any $13\frac{1}{2}$ -in. length of the joint must not exceed $1\frac{1}{8}$ -in. Paragraph M-4 limits the permissible porosity to that illustrated in Appendix A.

The porosity charts of Appendix A picture a maximum permissible void size of $\frac{1}{8}$ -in. at a minimum clear spacing of $4\frac{1}{2}$ -in. for a $1\frac{1}{8}$ -in. joint, and also show other combinations of pore size and spacing permissible in the hypothetical joint.

However, if the joint is to be used in such a manner that only a spot radiographic examination is required, then Paragraph (d) of UW-52 should be used rather than UW-51. UW-52 states that for such inspection a negative may reveal $\frac{3}{4}$ -in. elongated slag inclusions in a $1\frac{1}{2}$ -in. joint without providing cause for rejection if the total length of slag inclusions in any $6\frac{3}{4}$ -in. of the joint does not exceed $1\frac{1}{8}$ -in. No maximum limit of permissible porosity is specified in this case.

Both of these standards consider porosity and slag inclusions separately. The question arises as to how one appraises the total effect of such imperfections on the joint when both types occur simultaneously. For application to bridge construction,

the validity of segregating and evaluating each type of imperfection separately is questionable because of the inherent lack of precision in qualitative radiographic examination.

Moreover, except for thickness and alloy content, parallels between bridge and pressure vessel design are such that an inspector or design engineer would find it difficult to specify whether the spot or the total method of inspection should be used for a particular joint. Hence, as applied to bridges, the standards in the A.S.M.E. codes can serve only as arbitrary qualitative requirements necessary to secure that degree of craftsmanship which is essential in good welding practice.

As set forth in the previous paragraphs, the A.S.M.E. radiographic standards are qualitative rather than quantitative when applied to bridges. In efforts to circumvent this drawback, many agencies have resorted to Paragraph 607 (d) of A.W.S. Specification D2.0-47 as a radiographic standard for accepting or rejecting welded joints in bridge structures.

This too is somewhat arbitrary since the number of inclusions or voids permissible in a radiograph of a joint may vary either with the thickness of the joint or with some other interpretation of the inspector. Further, individually acceptable discontinuities may be so oriented as to appear as a single large discontinuity on a radiograph of a joint and thereby cause unnecessary rejection of the weld.

Experience has established that if radiographic standards are to help the shop and field inspector of bridge construction, they must be stated in a concise and explicit manner that will eliminate all uncertainties of interpretation and application.

To accomplish this, the standard shown by Figure 1 has been developed by revising and combining the A.S.M.E. standards for inclusions and porosity and the Paragraph 607 (a) of A.W.S. Specification D2.0-47 in such a way as to fit the requirements of welded bridge construction. This has been done in the following manner:

First, from A.S.M.E. Code UW-51, the maximum permissible inclusion size ($L=T/3$) for joint thicknesses in $\frac{1}{4}$ -in. increments up to $1\frac{1}{2}$ -in., versus the minimum permissible spacing ($6L$) assuming optimum intervals between inclusions was graphed as shown on Figure 2.

Second, from the same code, the maximum permissible inclusion size ($T/3$) for joint thickness in $\frac{1}{4}$ -in. increments up to $1\frac{1}{2}$ -in. versus the minimum permissible averaged spacing assuming non-ideal intervals was plotted on the same graph.

These limitations are outlined in the A.S.M.E. Pressure Vessel Code, Part UW-51, Section M, Paragraphs 2 and 3.

Third, the variables as taken from Appendix A of this code for porosity and illustrated therein under large unaligned porosity and large aligned porosity were plotted. Here the spacing for unaligned porosity was obtained from the square root of the quotient of the area as measured from the Appendix A illustration divided by the number of voids illustrated. The size of the voids was measured from the illustration.

Last, the variables were graphed as they might be interpreted from Paragraph 607 (a) of A.W.S. Specification D2.0-47. In this case it was interpreted that the maximum permissible length of a single discontinuity is $1/16$ -in. for all joint thicknesses,

and the maximum total length of all such in any square inch of weld section is limited to $3/8$ -in.

The A.S.M.E. standards on porosity and the interpretation of A.W.S. Specification D2.0-47 set forth in the previous paragraphs were eliminated since extrapolation of the A.S.M.E. standard for slag inclusions in the same range of inclusion size and spacing overlaps the first two, as can be seen from the graph.

This left the two A.S.M.E. standards as outlined in the foregoing paragraphs, for spacing of slag inclusion, (one based on $L=6L$ and the other on $T=12T$), which were averaged and shown by the line titled "Proposed Calif. Standard", and became the basis for the suggested system of radiographic standard interpretation. This line was replotted on a separate sheet (Figure 1). The allowable size of inclusion was plotted along this slope and a chart was constructed with the minimum distance between inclusions as the abscissa and with the joint thickness as the ordinate.

At this point an additional limitation to allow for the effect of edge distance and areas of restraint was incorporated. As yet, data accumulated has been insufficient to enable an engineered relationship to be established absolutely between the working stresses of a beam and the position of weld metal imperfections with relation to the sectional and load geometry of that beam. Nevertheless, it is obvious that some arbitrary limits in this direction are advisable.

Cited here is the paper of Reference 3. Nearly all the tests listed in this paper indicate the failures to be initiated at a discontinuity in the web adjacent to the tension flange or in the tension flange adjacent to the web. It is felt that this

paper confirms the importance of insuring that the tension flange adjacent to the web be as free of stress-raising discontinuities as possible.

Considering that a point of restraint in the joint, such as the junction of a stiffening member or web, and also that the free edges of a joint, may act as stress raisers in the same magnitude as large concentrations of slag in the weld, then they could be considered as a group of irregularly spaced slag inclusions. Section UW-51, M-3 of the A.S.M.E. code, states that the number of such irregularly spaced inclusions must be reduced by $1/2$ over that permissible for regularly spaced inclusions. Therefore, the minimum space between a flange (joint) edge or toe of web fillet weld and an inclusion was set 2 times greater than the minimum distance between interior inclusions. This distance, together with the length of the inclusion involved, and with an allowance for the thickness of the web fillets, determines the minimum flange width that will tolerate the maximum size of inclusion.

The standards set forth in this paper have been applied to a random sampling of project radiographs on file and are found to be practical. They were measured against both ease of interpretation and feasibility under conditions of normal job production as governed by modern welding practice and specifications.

Simulated examples of the application of various radiographic standards can be seen by Figures 4, 5, and 6. These examples show the allowable spacing of maximum and minimum sized inclusion under various standards as compared with the standard proposed by this paper.

Summary

1. The lack of a clear cut specification for radiography to be applied to welded highway bridges has led to some confusion and misunderstanding as to the value and use of radiography.
2. Radiography, if used intelligently, is well within the limits of acceptable economical inspection charges.
3. Radiography or some other nondestructive means of detection of internal defects is necessary to assure the integrity of a welded structural joint. Radiography is the most practical nondestructive method presently available.
4. Figure 1 in the Appendix presents a suggested standard to be used in interpreting radiographic films of primary stress carrying welded bridge butt joints.
5. Laboratory research is urged to further refine the standards suggested in this paper and also to furnish basic data to modify such standards for application to major compression carrying butt welds, web members, and secondary members.

Acknowledgement

Special acknowledgement is given to Paul G. Jonas, Welding Engineer of the California Division of Highways, and to members of his staff, Charles Kendrick and Robert Benson, for their valuable data analysis and practical development of the suggested radiographic standards.

Appreciation is also expressed to the members of the Structural Materials inspection staff of the Materials and Research Department, and the members of the Bridge Department of the California Division of Highways, as well as to various engineering and production personnel of the structural steel fabricating industry for their constructive criticism and other valuable contributions during the development of these standards.

Bibliography

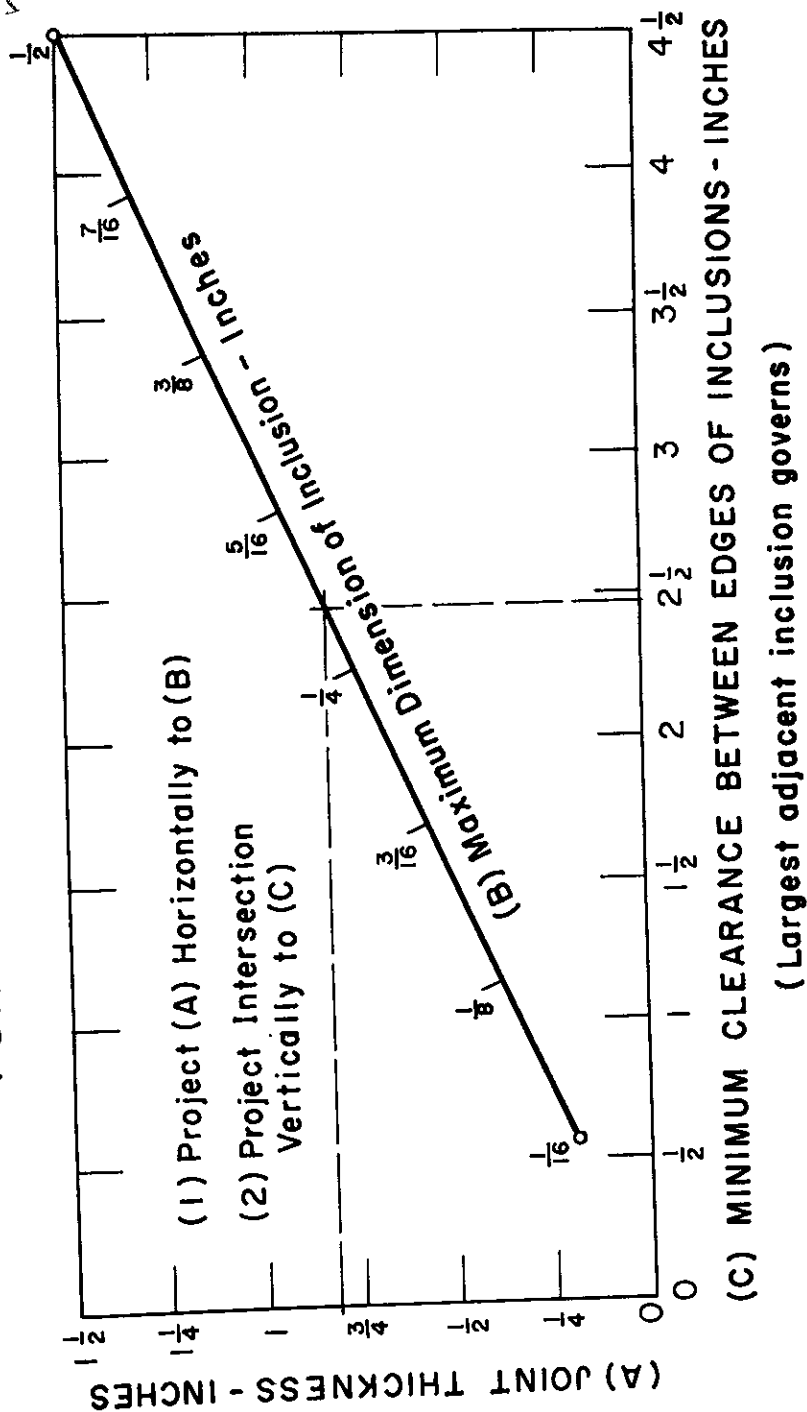
1. The Fatigue and Static Properties of Butt Welds in Structural Steels, by Harris and Nordmark of the University of Illinois, U. S. Army Engineers Contract No. DA-33-017-eng-221.
2. Fatigue and Static Properties of Welded Joints in Low Alloy Structural Steels, by Nordmark, Stallmeyer and Munse of the University of Illinois, U. S. Army Engineers Contract No. DA-33-017-eng-225.
3. The Behavior of Welded Built-up Beams Under Repeated Loads by Stallmeyer, Munse, and Goodall of the University of Illinois, January 1957 issue of the Welding Journal.
4. American Welding Society Specifications D2.0-47 and D2.0-56, Standard Specifications for Welded Highway and Railway Bridges.
5. American Society of Mechanical Engineers Boiler and Pressure Vessel Code 1952, Section VIII, Unfired Pressure Vessels.
6. Structural Welding Inspection by Beaton and Jonas of California Division of Highways, American Society of Civil Engineers Transactions, Paper 2735.
7. Tentative Reference Radiographs for Steel Welds; A.S.T.M. Designation: E 99; American Society for Testing Materials.
8. Collection of Reference Radiographs of Welds; International Institute of Welding, Tekniska Röntgencentralen, Sweden.
9. Welding Handbook, American Welding Society.

PROPOSED CALIFORNIA RADIOGRAPHIC STANDARD

All butt welds designed to carry primary stresses shall be subject to radiographic inspection. The presence of any of the following listed defects in excess of the limits indicated shall result in rejection of the weld as defective:

1. Cracks — no cracking shall be allowed regardless of length or location.
2. Overlaps, lack of penetration, incomplete fusion — none shall be allowed.
3. Inclusions; including slag, porosity, and other deleterious material, — less than $1/16$ " in greatest dimension shall be allowed if well dispersed such that the sum of the greatest dimensions of the inclusions in any linear inch of welded joint shall not exceed $3/8$ " and there shall be no inclusion within 1" of the edge of a joint or a point of restraint.
4. Inclusions; including slag, porosity, and other deleterious material, — $1/16$ " or larger in greatest dimension shall be allowed providing such defects do not exceed the limits indicated by the chart, Sheet 2, of this Standard.

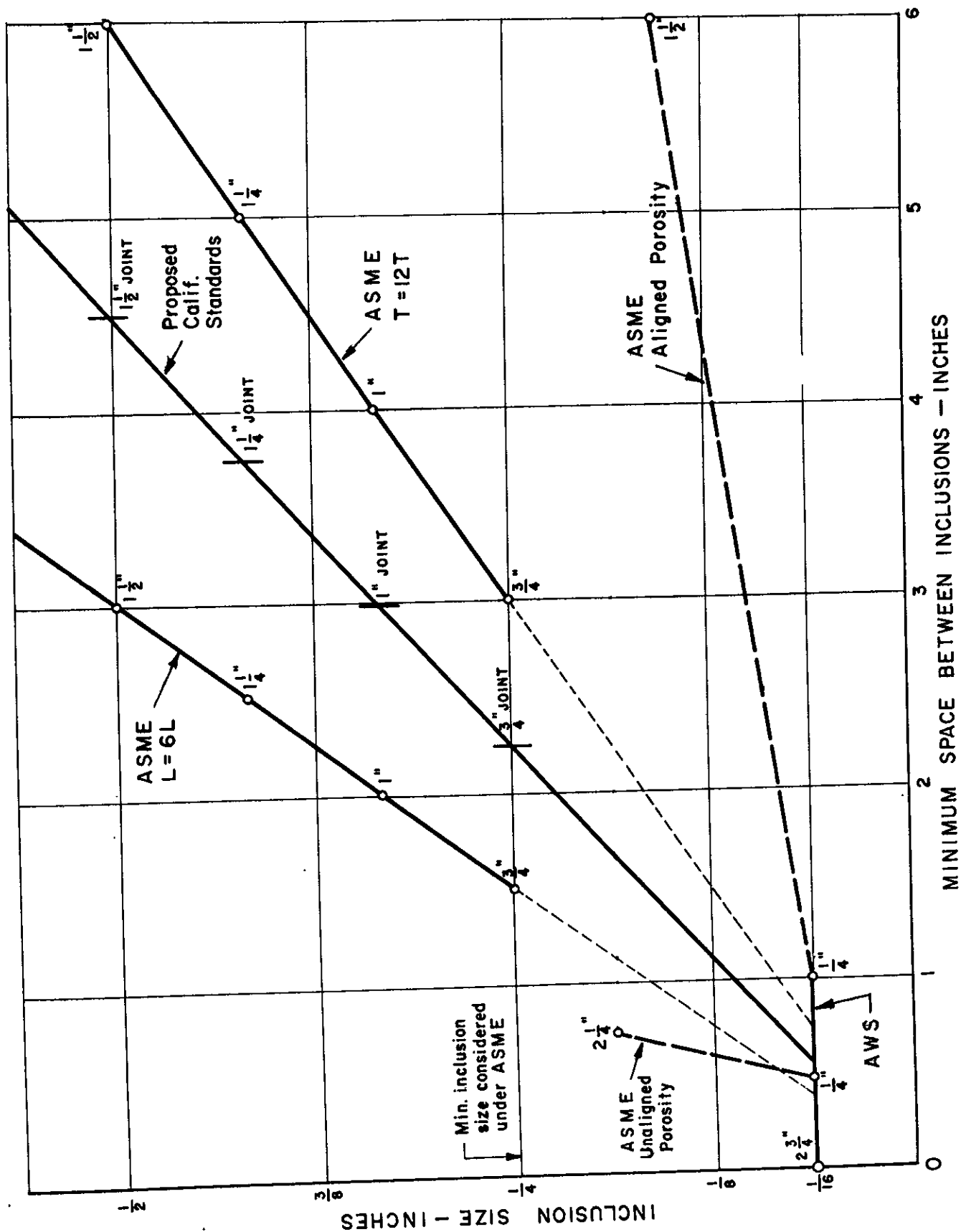
SUGGESTED CALIFORNIA RADIOGRAPHIC STANDARDS FOR ALLOWABLE INCLUSIONS



NOTE:

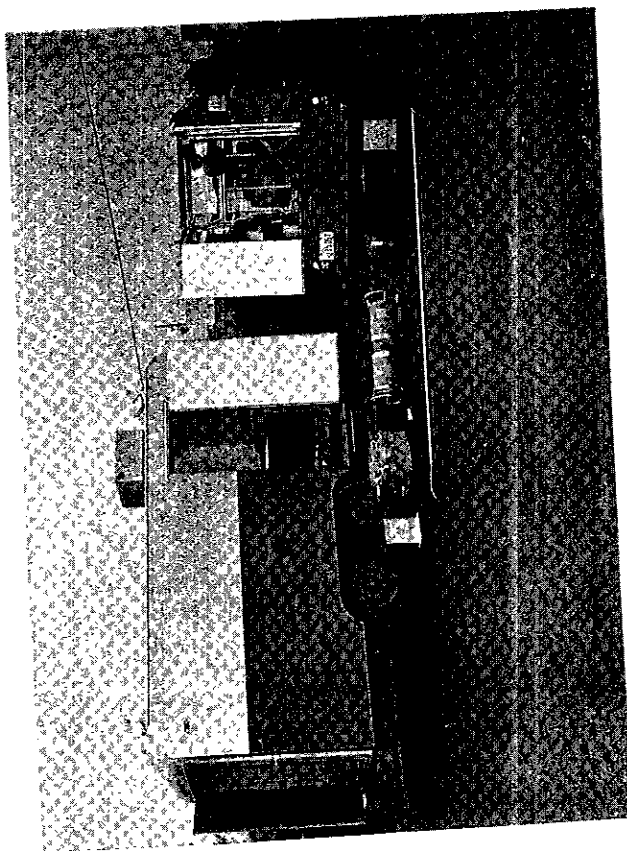
1. Minimum distance from edge of inclusion to free edge of plate or toe of flange fillet weld is twice the clearance between inclusions.
2. Inclusions with any dimension greater than 1/2" are not acceptable.
3. For joint thicknesses greater than 1-1/2", the minimum allowable dimension and spacing of inclusions shall be the same as for 1-1/2" joints.

Fig. 2

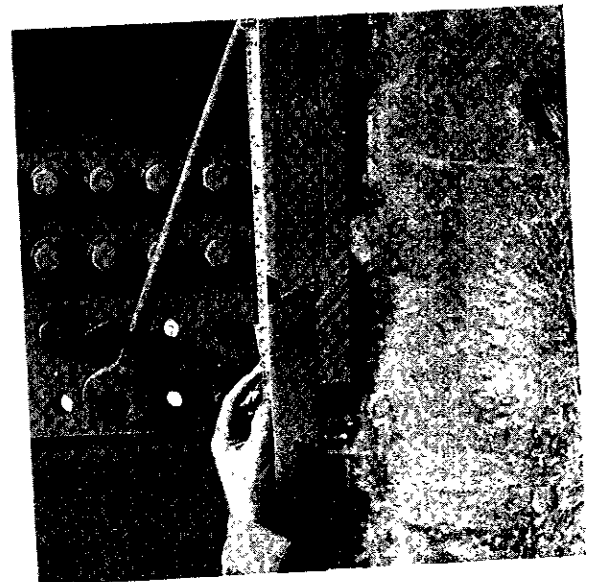




(2)



(1)



(3)

- (1) Radiographic Truck & Trailer showing in foreground tube & console and Cesium 137 & Cobalt 60 gamma ray source.
- (2) Shop fabrication showing two flange joints being radiographed simultaneously by using cobalt source suspended between the joints.
- (3) A typical bottom flange field splice using welded butt flange joint and high tensile bolted web. Showing fit up prior to welding and radiographic inspection.

Figure 3

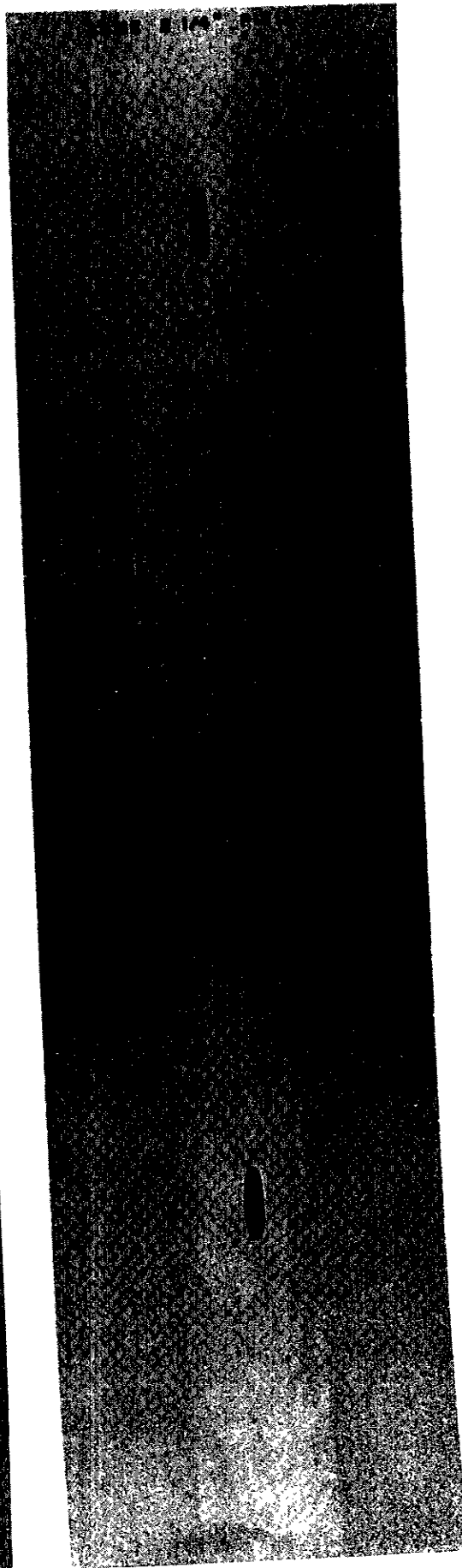
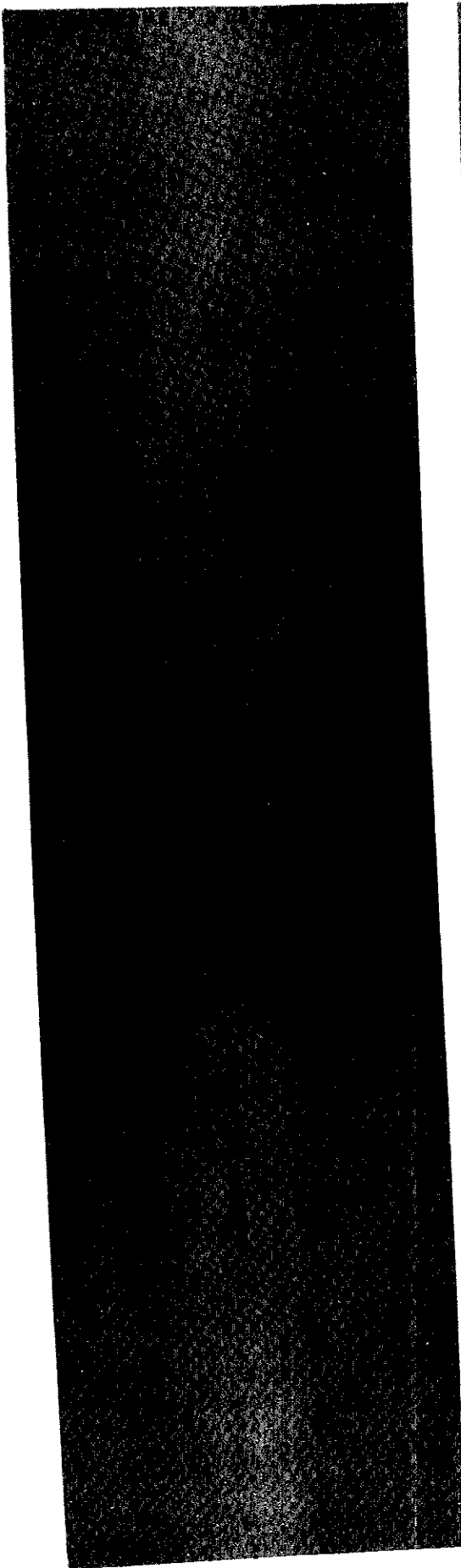
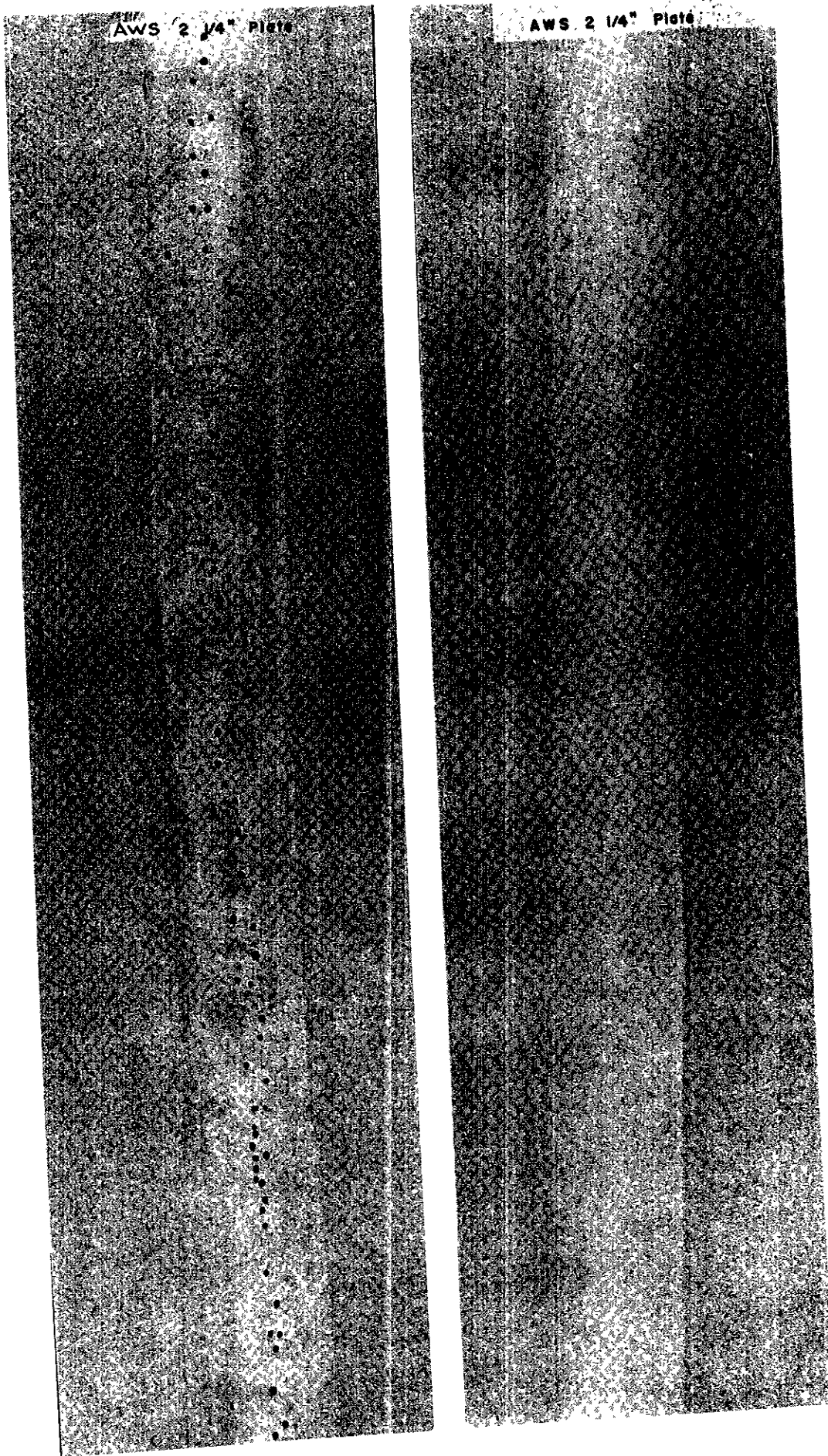


Figure 4

Simulated radiographs (reduced from $4\frac{1}{2}$ " x 17") showing two maximum conditions which might occur in an acceptable welded joint under ASME specifications UW51.

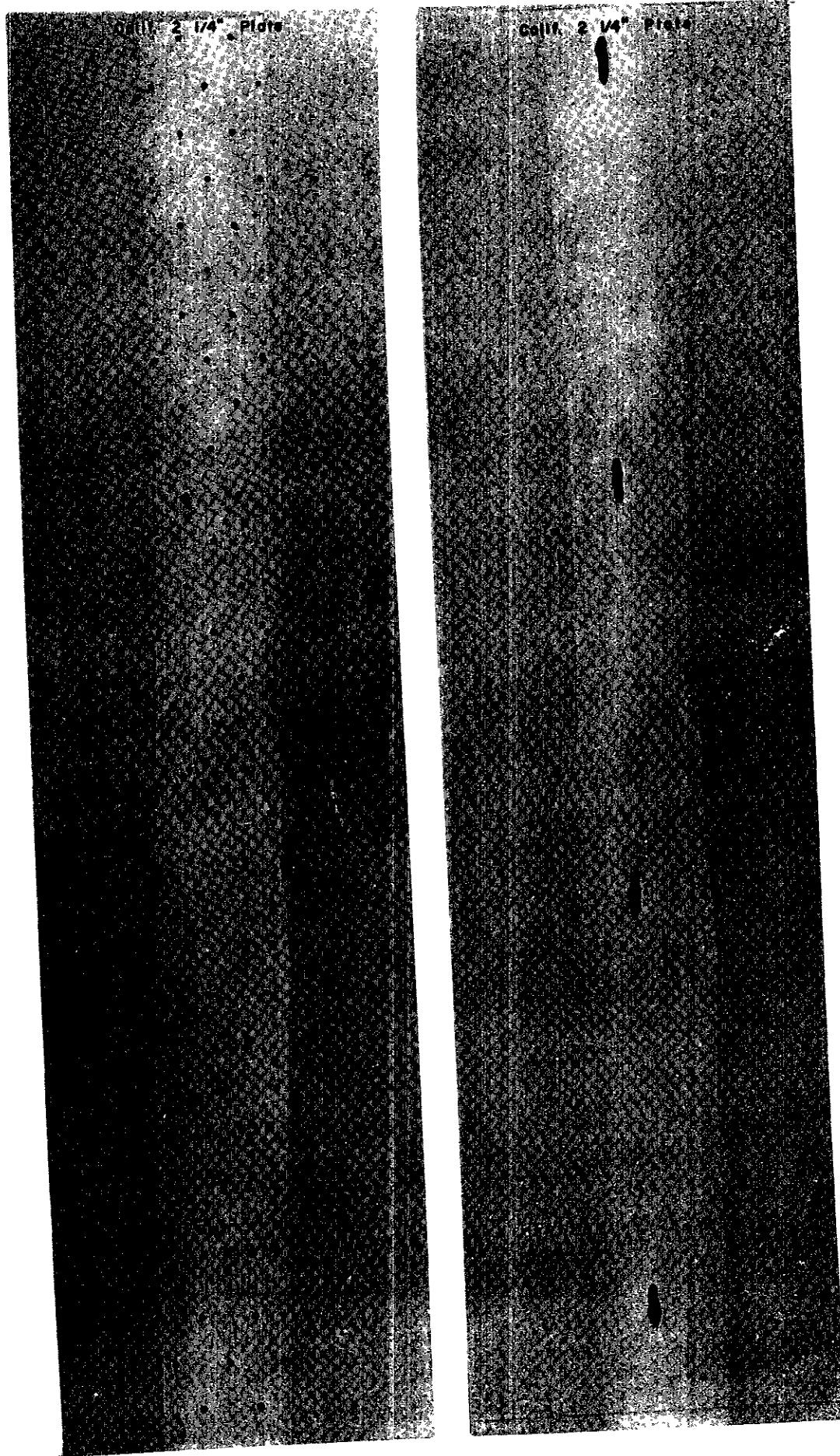
Top picture shows maximum condition of mixture of porosity and irregularly spaced large inclusions. Lower picture shows maximum allowable size and minimum spacing of large regularly spaced inclusions.



Simulated radiographs (reduced from $4\frac{1}{2}$ " x 17") showing two maximum conditions which might occur in an acceptable welded joint under an interpretation of AWS D2.0-47 (Article 607).

Top picture shows possible extreme condition of accumulation of $1/16$ " inclusions. Lower picture indicates condition of joint to be acceptable when considering inclusions larger than $1/16$ ".

Figure 6



Simulated radiographs (reduced from $4\frac{1}{2}'' \times 17''$) showing two maximum conditions which might occur in an acceptable welded joint under the Proposed California Radiographic Standards.

Top picture shows maximum allowable accumulation of $1/16''$ size inclusions. Lower picture shows maximum size ($1/2''$) and minimum spacing of this maximum allowable inclusion size of $1/2''$.